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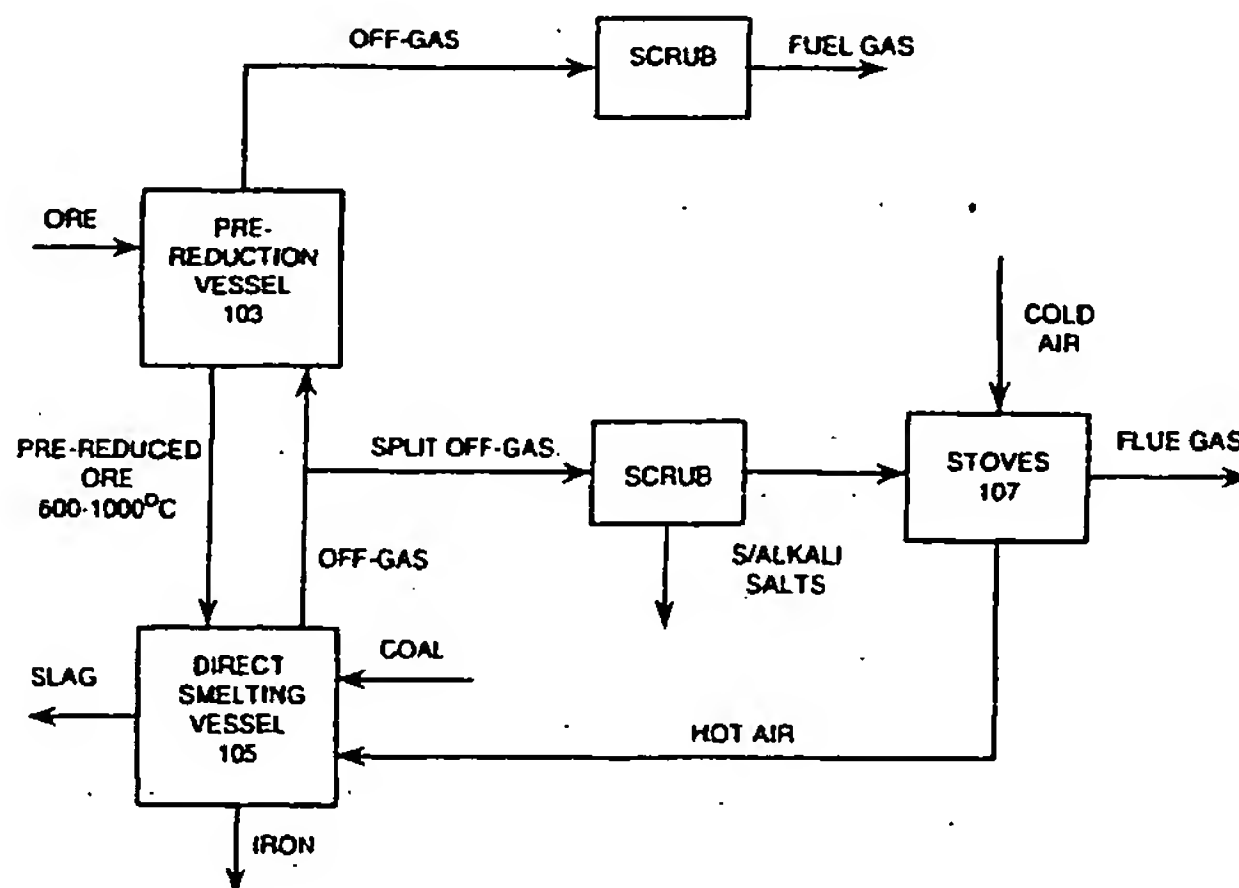
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(54) Title: A DIRECT SMELTING PROCESS



(57) Abstract: A process for direct smelting metalliferous feed material is disclosed. Iron oxides are partially reduced in a solid state in a pre-reduction vessel. The partially reduced iron oxides are smelted to molten iron in a direct smelting vessel which contains a molten bath of iron and slag and is supplied with a solid carbonaceous material as a source of reductant and energy and with an oxygen containing gas for post-combusting carbon monoxide and hydrogen generated in the vessel. The direct smelting step generates an off-gas that contains sulphur and the off-gas is released from the direct smelting vessel. Part only of the off-gas released from the direct smelting vessel is used in the pre-reduction step to pre-reduce iron oxides in the pre-reduction vessel. Part only of the off-gas is used in the pre-reduction step in order to control the amount of sulphur that is returned with the partially reduced iron oxides to the direct smelting vessel.

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A DIRECT SMELTING PROCESS

5 The present invention relates to a process for producing molten iron from a metalliferous feed material, such as ores, partly reduced ores, and metal-containing waste streams, in a molten bath-based direct smelting process for producing molten iron from a metalliferous feed material.

10 The term "direct smelting process" is understood to mean a process that produces a molten material, in this case iron, from a metalliferous feed material.

15 One known molten bath-based direct smelting process for producing molten ferrous metal is the DIOS process. The DIOS process includes a pre-reduction stage and a smelt reduction stage. In the DIOS process ore (-8mm) is pre-heated (750°C) and pre-reduced (10 to 30%) in bubbling fluidised beds using offgas from a smelt reduction vessel which contains a molten bath of metal and slag, with
20 the slag forming a deep layer on the metal. The fine (-0.3mm) and coarse (-8 mm) components of the ore are separated in the pre-reduction stage of the process and the -0.3 mm is collected in a cyclone and injected into the
25 smelt reduction furnace with nitrogen whilst the coarse ore is charged by gravity. Pre-dried coal is charged directly to the smelt reduction furnace from the top of the vessel. The coal decomposes into char and volatile matter in the slag layer and the ore dissolves in the molten slag and
30 forms FeO. The FeO is reduced at the slag/metal and slag/char interfaces to produce iron. The carbon monoxide generated at the metal/slag and slag/char interface generates a foaming slag. Oxygen is blown through a specially designed lance that introduces the oxygen inside
35 the foamed slag and improves secondary combustion. Oxygen jets burn carbon monoxide that is generated with the smelting reduction reactions, thereby generating heat that

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is transferred first to the molten slag and then to the slag/metal interface by the strong stirring effect of bottom blowing gas. The stirring gas introduced into the hot metal bath from the bottom or side of the smelt reduction vessel improves heat transfer efficiency and increases the slag/metal interface for reduction and therefore the vessel productivity and thermal efficiency. However, injection rates must be limited as strong stirring lowers secondary combustion due to increased interaction between the oxygen jet and metal droplets in the slag with subsequent lowering of productivity and increased refractory wear. Slag and metal are tapped periodically.

Another known direct smelting process for producing molten ferrous metal is the Romelt process. The Romelt process is based on the use of a large volume, highly agitated slag bath as the medium for smelting metalliferous feed material to metal in a smelt reduction vessel and for post-combusting gaseous reaction products and transferring the heat as required to continue smelting metalliferous feed material. The metalliferous feed material, coal, and fluxes are gravity fed into the slag bath via an opening in the roof of the vessel. The Romelt process includes injecting a primary blast of oxygen-enriched air into the slag via a lower row of tuyeres to cause necessary slag agitation and injection of oxygen-enriched air or oxygen into the slag via an upper row of tuyeres to promote post-combustion. The molten metal produced in the slag moves downwardly and forms a metal layer and is discharged via a forehearth. In the Romelt process the metal layer is not an important reaction medium.

Another known direct smelting process for producing molten ferrous metal is the AISI process. The AISI process includes a pre-reduction stage and a smelt reduction stage. In the AISI process pre-heated and

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partially pre-reduced iron ore pellets, coal or coke breeze and fluxes are top charged into a pressurised smelt reactor which contains a molten bath of metal and slag. The coal devolatilises in the slag layer and the iron ore pellets
5 dissolve in the slag and then are reduced by carbon (char) in the slag. The process conditions result in slag foaming. Carbon monoxide and hydrogen generated in the process are post combusted in or just above the slag layer to provide the energy required for the endothermic
10 reduction reactions. Oxygen is top blown through a central, water cooled lance and nitrogen is injected through tuyeres at the bottom of the reactor to ensure sufficient stirring to facilitate heat transfer of the post combustion energy to the bath. The process offgas is de-
15 dusted in a hot cyclone before being fed to a shaft type furnace for pre-heating and pre-reduction of the pellets to FeO or wustite.

Another known direct smelting process which,
20 unlike the above-described processes, relies on a molten metal layer as a reaction medium, is generally referred to as the HIs melt process and includes the steps of:

- 25 (a) forming a molten bath having a metal layer and a slag layer on the metal layer in a direct smelting vessel;
- (b) injecting metalliferous feed material and coal into the metal layer via a plurality of
30 lances/tuyeres;
- (c) smelting metalliferous material to metal in the metal layer;
- 35 (d) causing molten material to be projected as splashes, droplets, and streams above a quiescent surface of the molten bath to form

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a transition zone; and

- 5 (d) injecting an oxygen-containing gas into the vessel via one or more than one lance/tuyere to post-combust reaction gases released from the molten bath, whereby ascending and thereafter descending splashes, droplets and streams of molten material in the transition zone facilitate heat transfer to the molten bath, and whereby the transition zone minimises heat loss from the vessel via the side walls in contact with the transition zone.
- 10

15 A preferred form of the Hismelt process is characterized by forming the transition zone by injecting carrier gas, metalliferous feed material, coal, and fluxes into the bath through lances that extend downwardly and inwardly through side walls of the vessel so that the carrier gas and the solid material penetrate the metal layer and cause molten material to be projected from the bath.

20

This form of the Hismelt process is an improvement over earlier forms of the process which form the transition zone by bottom injection of carrier gas and coal through tuyeres into the bath which cause droplets and splashes and streams of molten material to be projected from the bath.

25

30 The Romelt, DIOS, AISI and Hismelt direct smelting processes can use coal as the source of energy and reductant. This is an advantage of the direct smelting processes over blast furnace technology which requires coke as the source of energy/reductant.

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The Romelt, DIOS , AISI and Hismelt direct

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smelting processes can operate with a wide range of metalliferous feed materials.

Iron ore is the major source of metalliferous feed materials for producing molten iron via the Romelt, DIOS, AISI, and Hismelt processes.

One process option for the direct smelting processes is to supply iron ore directly to direct smelting vessels.

Another process option is to pre-heat and partially reduce iron ore in a solid state in pre-reduction vessels (which could be a shaft furnace or a fluidised bed or any other suitable vessel), transfer the pre-heated/partially reduced iron ore to direct smelting vessels containing a molten bath of iron and slag, and smelt the pre-heated/partially reduced iron ore to molten iron in the direct smelting vessels. This process option may also include using off-gas from the direct smelting vessels to pre-heat/pre-reduce iron ore in the pre-reduction vessels. One advantage of the process option is that it provides an opportunity to minimise total energy consumption. One disadvantage of the process option is that undesirable impurities, typically coal-derived impurities such as sulphur and alkali salts, which volatilise in direct smelting vessels and are discharged as part of the off-gas, return to the direct smelting vessels with the pre-heated/partially reduced iron ore and accumulate in the vessels. Specifically, sulphur reacts with FeO in the pre-reduction vessels and forms FeS and alkali salts condense in the pre-reduction vessels, and the FeS and condensed alkali salts are transferred to the direct smelting vessels with the pre-heated/partially reduced iron ore. The return of FeS into a direct smelting vessel disrupts the reaction sites of the smelting process and can significantly affect production. One solution to

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this issue is to increase the temperature of the medium for smelting. However, this leads to increased refractory wear and if pursued too far leads to the partitioning of phosphorus into the metal rather than the slag, and this is
5 a major disadvantage.

An object of the present invention is to alleviate the disadvantage of the known 2-stage direct smelting process described in the preceding paragraph and
10 in particular where the smelting medium is metal.

According to the present invention there is provided a process for direct smelting metalliferous feed material which includes the steps of:

15

(a) partially reducing iron oxides in a solid state in a pre-reduction vessel and producing partially reduced iron oxides;

20

(b) direct smelting partially reduced iron oxides produced in step (a) to molten iron in a direct smelting vessel which contains a molten bath of iron and slag and is supplied with a solid carbonaceous material as a
25 source of reductant and energy and with an oxygen-containing gas for post-combusting carbon monoxide and hydrogen generated in the vessel;

30

(c) generating an off-gas that contains sulphur in direct smelting step (b) and releasing the off-gas from the direct smelting vessel; and

35

(d) using only part of the off-gas released from the direct smelting vessel in pre-reduction step (a) to pre-reduce iron oxides in the

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pre-reduction vessel to control the amount of sulphur that is returned to the direct smelting vessel from the pre-reduction vessel.

5

The effect of step (d) of using only part rather than all of the off-gas from the direct smelting vessel in pre-reduction step (a) is to at least minimise the rate of build-up of undesirable impurities, typically coal-derived impurities, in the direct smelting vessel. As is indicated above, a disadvantage of the known 2-stage direct smelting process is that a number of undesirable impurities, typically coal-derived impurities such as sulphur and alkali salts, that are volatilised in direct smelting vessels are recovered in pre-reduction vessels and thereafter are returned to the direct smelting vessels.

Preferably step (d) includes controlling the amount of off-gas released from the direct smelting vessel and used in pre-reduction step (a) so that the amount of sulphur in molten iron produced in direct smelting step (b) is less than 0.2 wt% of the total weight of the molten iron.

Preferably the process includes processing the remainder of the off-gas released from the direct smelting vessel for heating and/or for power generation without returning the majority of the sulphur in this part of the off-gas to the direct smelting vessel.

30

Preferably direct smelting step (b) includes injecting pre-heated air or oxygen-enriched air into the direct smelting vessel as the oxygen-containing gas.

More preferably the process includes using a first stream of the off-gas from the direct smelting vessel in pre-reduction step (a) and using a second stream of the

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off-gas as a source of energy for heating air or oxygen-enriched air before supplying the air or oxygen-enriched air to the direct smelting vessel.

5 Preferably the second stream includes at least 20% by volume of the off-gas released from the direct smelting vessel.

10 More preferably the second stream includes at least 30 vol.% of the off-gas released from the direct smelting vessel.

15 It is preferred particularly that the second stream includes at least 40 vol.% of the off-gas released from the direct smelting vessel.

20 Preferably the process includes removing entrained sulphur and alkali salts from the second stream prior to using the second stream as the source of energy for heating air or oxygen-enriched air.

 Preferably the oxygen-enriched air contains less than 50 volume % oxygen.

25 Preferably pre-reduction step (a) pre-heats the iron ore to a temperature in the range of 600-1000°C.

30 Preferably the off-gas from pre-reduction step (a) is used as a fuel gas for heating or power generation.

 Smelting step (b) may include any suitable direct smelting process and use either the metal or the slag as the smelting medium.

35 Preferably smelting step (b) includes using the metal as a smelting medium and more preferably as the principal smelting medium.

Preferably smelting step (b) includes direct smelting partially reduced iron oxides in accordance with the HIs melt process which includes the steps of:

- (i) forming the molten bath with a molten iron layer and a molten slag layer on the iron layer in the direct smelting vessel;
- (ii) injecting the partially reduced iron oxides and coal into the iron layer via a plurality of lances/tuyeres;
- (iii) smelting the partially reduced iron oxides to molten iron in the iron layer;
- (iv) causing molten material to be projected as splashes, droplets, and streams into a space above a nominal quiescent surface of the molten bath and forming a transition zone; and
- (v) injecting the oxygen-containing gas into the direct smelting vessel via one or more than one lance/tuyere and post-combusting carbon monoxide and hydrogen released from the molten bath, whereby the ascending and thereafter descending splashes, droplets, and streams of molten material in the transition zone facilitate heat transfer to the molten bath, and whereby the transition zone minimises heat loss from the vessel via a side wall of the vessel that is in contact with the transition zone.

The term "quiescent surface" in the context of the molten bath is understood herein to mean the surface of

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the molten bath under process conditions in which there is no gas/solids injection and therefore no bath agitation.

5 The present invention is described further by way of example with reference to the accompanying drawings, of which:

Figure 1 is a flow sheet, in largely schematic form, of one preferred embodiment of the process of the present invention; and

10 Figure 2 is a vertical section through a preferred form of a direct smelting vessel for use in the process illustrated in Figure 1.

15 With reference to Figure 1, iron ore, typically in the form of fines is heated and partially reduced in a pre-reduction vessel 103 and is then transferred at a temperature in the range of 600-1000°C to a direct smelting vessel 105 and smelted to molten iron in a molten bath in that vessel.

Coal, fluxes, and oxygen-enriched air are supplied to the direct smelting vessel 105. The coal is provided as a source of energy and reductant; the oxygen-enriched air is provided to post-combust combustible reaction products generated in the process; and the flux is provided to form slag.

30 The pre-reduction vessel 103 may be of any suitable type and configuration for the iron ore feed material. For example, if the iron ore feed is lump ore, typically the pre-reduction vessel is a shaft furnace. Further, if the iron ore feed is fines, typically the pre-reduction vessel is a fluidised bed-based furnace.

35 The iron ore feed material is heated and

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partially reduced in the pre-reduction vessel 103 by off-gas released from the direct smelting vessel 105. The off-gas passes out of the pre-reduction vessel 103 and may be used as a low energy fuel gas for heating or power generation (not shown).

The off-gas may be transferred directly from the direct smelting vessel 105 to the pre-reduction vessel 103. In that case, the extent of heating and reduction in the pre-reduction vessel 103 is a function of the temperature and composition of the off-gas, which in turn is a function of the direct smelting process operating in the direct smelting vessel 105.

The off-gas may also be transferred from the direct smelting vessel 105 to the pre-reduction vessel 103 via a gas reformer (not shown) or other means which pre-condition the off-gas upstream of the pre-reduction vessel 103.

In accordance with the present invention, the off-gas from the direct smelting vessel 105 is split into two (or more) streams, with one stream being transferred directly or indirectly to the pre-reduction vessel 103 as described in the preceding paragraphs, and with the other stream being used on the combustion side of stoves 107 which pre-heat oxygen-enriched air for post-combusting reaction products in the direct smelting vessel 105.

In the preferred embodiment of the present invention the purpose of splitting the off-gas stream is two-fold.

Firstly, transferring only part of the off-gas stream to the pre-reduction vessel 103 reduces the rate of accumulation in the direct smelting vessel 105 of undesirable impurities, typically coal-derived impurities

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such as sulphur and alkali salts, that volatilise in the direct smelting process and are recovered in the pre-reduction step and are returned to the direct smelting vessel 105 with incoming partially reduced iron ore.

5

Secondly, using part of the off-gas stream to heat the stoves 107 is beneficial from the viewpoint of minimising total energy consumption. This second advantage applies particularly to air-based direct smelting processes
10 where there is usually more off-gas than is required for heating/reducing iron ore in the pre-reduction vessel 103 and splitting the off-gas does not adversely affect the operation of the pre-reduction vessel 103.

15

The direct smelting process operating in the direct smelting vessel 105 may be any suitable process and may be a cold oxygen-based system.

20

The preferred direct smelting process operated in the direct smelting vessel is the HIs melt process as described in general terms hereinafter with reference to Figure 2 and in more detail in International application PCT/AU99/00538 in the name of the applicant, and the disclosure in the patent specification lodged with the
25 International application is incorporated herein by cross-reference.

30

In the context of the present invention, the direct smelting process described in the International application is based on:

35

(a) forming a molten bath having a molten iron layer and a molten slag layer on the iron layer in the direct smelting vessel 105;

(b) injecting the partially reduced iron ore and coal and fluxes into the iron layer via a

plurality of lances/tuyeres;

- (c) smelting the partially reduced iron ore to molten iron in the metal layer;

5

- (d) causing molten material to be projected as splashes, droplets, and streams into a space above a normal quiescent surface of the molten bath and forming a transition zone; and

10

- (e) injecting the heated oxygen-enriched air into the direct smelting vessel 105 via one or more than one lance/tuyere and post-combusting reaction gases, typically carbon monoxide and hydrogen, released from the molten bath and generating temperatures of the order of 2000°C or higher in the transition zone, whereby the ascending and thereafter descending splashes, droplets and streams of molten material in the transition zone facilitate heat transfer to the molten bath, and whereby the transition zone minimises heat loss from the vessel via the side walls in contact with the transition zone.

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The direct smelting vessel 105 may be any suitable vessel.

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The preferred direct smelting vessel is the vessel described in general terms hereinafter with reference to Figure 2 and in more detail in International application PCT/AU99/00537 in the name of the applicant and the disclosure in the patent specification lodged with the International application is incorporated herein by cross-reference.

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The vessel 105 shown in Figure 2 has a hearth that includes a base 3 and sides 55 formed from refractory bricks; side walls 5 which form a generally cylindrical barrel extending upwardly from the sides 55 of the hearth and which include an upper barrel section 51 and a lower barrel section 53; a roof 7; an outlet 9 for off-gases; a forehearth 77 for discharging molten metal continuously; a forehearth connection 71 that interconnects the hearth and the forehearth 77; and a tap-hole 61 for discharging molten slag.

In use, under steady-state process conditions, the vessel 105 contains the molten bath which includes a layer 15 of molten iron and a layer 16 of molten slag on the iron layer 15. The arrow marked by the numeral 17 indicates the position of the nominal quiescent surface of the iron layer 15 and the arrow marked by the numeral 19 indicates the position of nominal quiescent surface of the slag layer 16. The term "quiescent surface" is understood to mean the surface when there is no injection of gas and solids into the vessel.

The vessel 105 also includes 2 solids injection lances/tuyeres 11 extending downwardly and inwardly at an angle of 30-60° to the vertical through the side walls 5 and into the slag layer 16. The position of the lances/tuyeres 11 is selected so that the lower ends are above the quiescent surface 17 of the iron layer 15 under steady-state process conditions.

In use, under steady-state process conditions, the partially reduced iron ore, coal, and fluxes (typically lime and magnesia) entrained in a carrier gas (typically N₂) are injected into the iron layer 15 via the lances/tuyeres 11. The momentum of the solid material/carrier gas causes the solid material and gas to

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penetrate the iron layer 15. Carbon partially dissolves into the metal and partially remains as solid carbon. The pre-reduced iron ore is smelted to iron and the smelting reaction generates carbon monoxide gas. The gases
5 transported into the iron layer 15 and generated via smelting produce significant buoyancy uplift of molten iron, solid carbon, and slag (drawn into the iron layer 15 as a consequence of solid/gas/injection) from the iron layer 15 which generates an upward movement of splashes,
10 droplets and streams of molten material, and these splashes, and droplets, and streams entrain slag as they move through the slag layer 16.

The buoyancy uplift of molten metal, solid carbon
15 and slag causes substantial agitation in the iron layer 15 and the slag layer 16, with the result that the slag layer 16 expands in volume and has a surface indicated by the arrow 30. The extent of agitation is such that there is reasonably uniform temperature in the metal and the slag
20 regions - typically, 1450 - 1550°C with a temperature variation of the order of 30° in each region.

In addition, the upward movement of splashes, droplets and streams of molten material caused by the
25 buoyancy uplift of molten iron, solid carbon, and slag extends into the top space 31 above the molten material in the vessel and:

- (a) forms a transition zone 23; and
30
- (b) projects some molten material (predominantly slag) beyond the transition zone and onto the part of the upper barrel section 51 of the side walls 5 that is above the
35 transition zone 23 and onto the roof 7.

In general terms, the slag layer 16 is a liquid

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continuous volume, with gas bubbles therein, and the transition zone 23 is a gas continuous volume with splashes, droplets, and streams of molten metal and slag.

5 The vessel 105 further includes a lance 13 for injecting the heated oxygen-enriched air into the vessel 105. The lance 13 is centrally located and extends vertically downwardly into the vessel. The position of the lance 13 and the gas flow rate through the lance 13 are
10 selected so that under steady-state process conditions the oxygen-containing gas penetrates the central region of the transition zone 23 and maintains an essentially metal/slag free space 25 around the end of the lance 13.

15 In use, under steady-state process conditions, the injection of the oxygen-containing gas via the lance 13 post-combusts- reaction gases CO and H₂ in the transition zone 23 and in the free space 25 around the end of the lance 13 and generates high temperatures of the order of
20 2000°C or higher in the gas space. The heat is transferred to the ascending and descending splashes droplets, and streams, of molten material in the region of gas injection and the heat is then partially transferred to the iron layer 15 when the metal/slag returns to the iron layer 15.

25 The free space 25 is important to achieving high levels of post combustion because it enables entrainment of gases in the space above the transition zone 23 into the end region of the lance 13 and thereby increases exposure
30 of available reaction gases to post combustion.

 The combined effect of the position of the lance 13, gas flow rate through the lance 13, and upward movement of splashes, droplets and streams of molten material is to
35 shape the transition zone 23 around the lower region of the lance 13 - generally identified by the numerals 27. This shaped region provides a partial barrier to heat transfer

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by radiation to the side walls 5.

Moreover, under steady-state process conditions, the ascending and descending droplets, splashes and streams of material is an effective means of transferring heat from the transition zone 23 to the molten bath with the result that the temperature of the transition zone 23 in the region of the side walls 5 is of the order of 1450°C-1550°C.

10

The vessel 105 is constructed with reference to the levels of the iron layer 15, the slag layer 16, and the transition zone 23 in the vessel 105 when the process is operating under steady-state process conditions and with reference to splashes, droplets and streams of molten material that are projected into the top space 31 above the transition zone 23 when the process is operating under steady-state operating conditions, so that:

20

(a) the hearth and the lower barrel section 53 of the side walls 5 that contact the iron/slag layers 15/16 are formed from bricks of refractory material (indicated by the cross-hatching in the figure);

25

(b) at least part of the lower barrel section 53 of the side walls 5 is backed by water cooled panels 8; and

30

(c) the upper barrel section 51 of the side walls 5 and the roof 7 that contact the transition zone 23 and the top space 31 are formed from water cooled panels 57, 59.

35

Each water cooled panel 8, 57, 59 (not shown) in

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the upper barrel section 51 of the side walls 5 has parallel upper and lower edges and parallel side edges and is curved so as to define a section of the cylindrical barrel. Each panel includes an inner water cooling pipe and an outer water cooling pipe. The pipes are formed into a serpentine configuration with horizontal sections interconnected by curved sections. Each pipe further includes a water inlet and a water outlet. The pipes are displaced vertically so that the horizontal sections of the outer pipe are not immediately behind the horizontal sections of the inner pipe when viewed from an exposed face of the panel, ie the face that is exposed to the interior of the vessel. Each panel further includes a rammed refractory material which fills the spaces between the adjacent horizontal sections of each pipe and between the pipes. Each panel further includes a support plate which forms an outer surface of the panel.

The water inlets and the water outlets of the pipes are connected to a water supply circuit (not shown) which circulates water at high flow rate through the pipes.

Many modifications may be made to the preferred embodiment described above without departing from the spirit and scope of the present invention.

CLAIMS:

1. A process for direct smelting metalliferous feed material which includes the steps of:

- 5
- (a) partially reducing iron oxides in a solid state in a pre-reduction vessel and producing partially reduced iron oxides;
- 10
- (b) direct smelting partially reduced iron oxides produced in step (a) to molten iron in a direct smelting vessel which contains a molten bath of iron and slag and is supplied with a solid carbonaceous material as a
- 15
- source of reductant and energy and with an oxygen-containing gas for post-combusting carbon monoxide and hydrogen generated in the vessel;
- 20
- (c) generating an off-gas that contains sulphur in direct smelting step (b) and releasing the off-gas from the direct smelting vessel; and
- 25
- (d) using only part of the off-gas released from the direct smelting vessel in pre-reduction step (a) to pre-reduce iron oxides in the pre-reduction vessel to control the amount of sulphur that is returned to the direct
- 30
- smelting vessel from the pre-reduction vessel.

2. The process defined in claim 1 wherein step (d) includes controlling the amount of off-gas released from

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the direct smelting vessel and used in pre-reduction step (a) so that the amount of sulphur in molten iron produced in direct smelting step (b) is less than 0.2 wt% of the

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total weight of the molten iron.

3. The process defined in claim 1 or claim 2 includes processing the remainder of the off-gas released from the direct smelting vessel for heating and/or for power generation without returning the majority of the sulphur in this part of the off-gas to the direct smelting vessel.
4. The process defined in any one of the preceding claims includes using a first stream of the off-gas from the direct smelting vessel in pre-reduction step (a) and using a second stream of the off-gas as a source of energy for heating air or oxygen-enriched air before supplying the air or oxygen-enriched air to the direct smelting vessel.
5. The process defined in claim 4 wherein the second stream includes at least 20% by volume of the off-gas released from the direct smelting vessel.
6. The process defined in claim 5 wherein the second stream includes at least 30 vol.% of the off-gas released from the direct smelting vessel.
7. The process defined in claim 6 wherein the second stream includes at least 40 vol.% of the off-gas released from the direct smelting vessel.
8. The process defined in any one of claims 4 to 7 includes removing entrained sulphur and alkali salts from the second stream prior to using the second stream as the source of energy for heating air or oxygen-enriched air.
9. The process defined in any one of the preceding claims wherein the oxygen-containing gas is air or oxygen-enriched air containing less than 50 volume % oxygen.

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10. The process defined in claim 9 includes pre-heating the air or oxygen enriched air for use in direct smelting step (b).

5 11. The process defined in any one of the preceding claims wherein pre-reduction step (a) pre-heats the iron ore to a temperature in the range of 600-1000°C.

12. The process defined in any one of the preceding
10 claims includes releasing the off-gas from pre-reduction step (a) and using the off-gas as a fuel gas for heating or power generation.

13. The process defined in any one of the preceding
15 claims wherein smelting step (b) includes direct smelting partially reduced iron oxides in accordance with the steps of:

- 20 (i) forming the molten bath with a molten iron layer and a molten slag layer on the iron layer in the direct smelting vessel;
- (ii) injecting the partially reduced iron oxides and coal into the iron layer via a plurality of lances/tuyeres;
- 25 (iii) smelting the partially reduced iron oxides to molten iron in the iron layer;
- (iv) causing molten material to be projected as
30 splashes, droplets, and streams into a space above a nominal quiescent surface of the molten bath and forming a transition zone; and
- 35 (v) injecting the oxygen-containing gas into the direct smelting vessel via one or more than one lance/tuyere and post-combusting carbon

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monoxide and hydrogen released from the molten bath, whereby the ascending and thereafter descending splashes, droplets, and streams of molten material in the transition zone facilitate heat transfer to the molten bath, and whereby the transition zone minimises heat loss from the vessel via a side wall of the vessel that is in contact with the transition zone.

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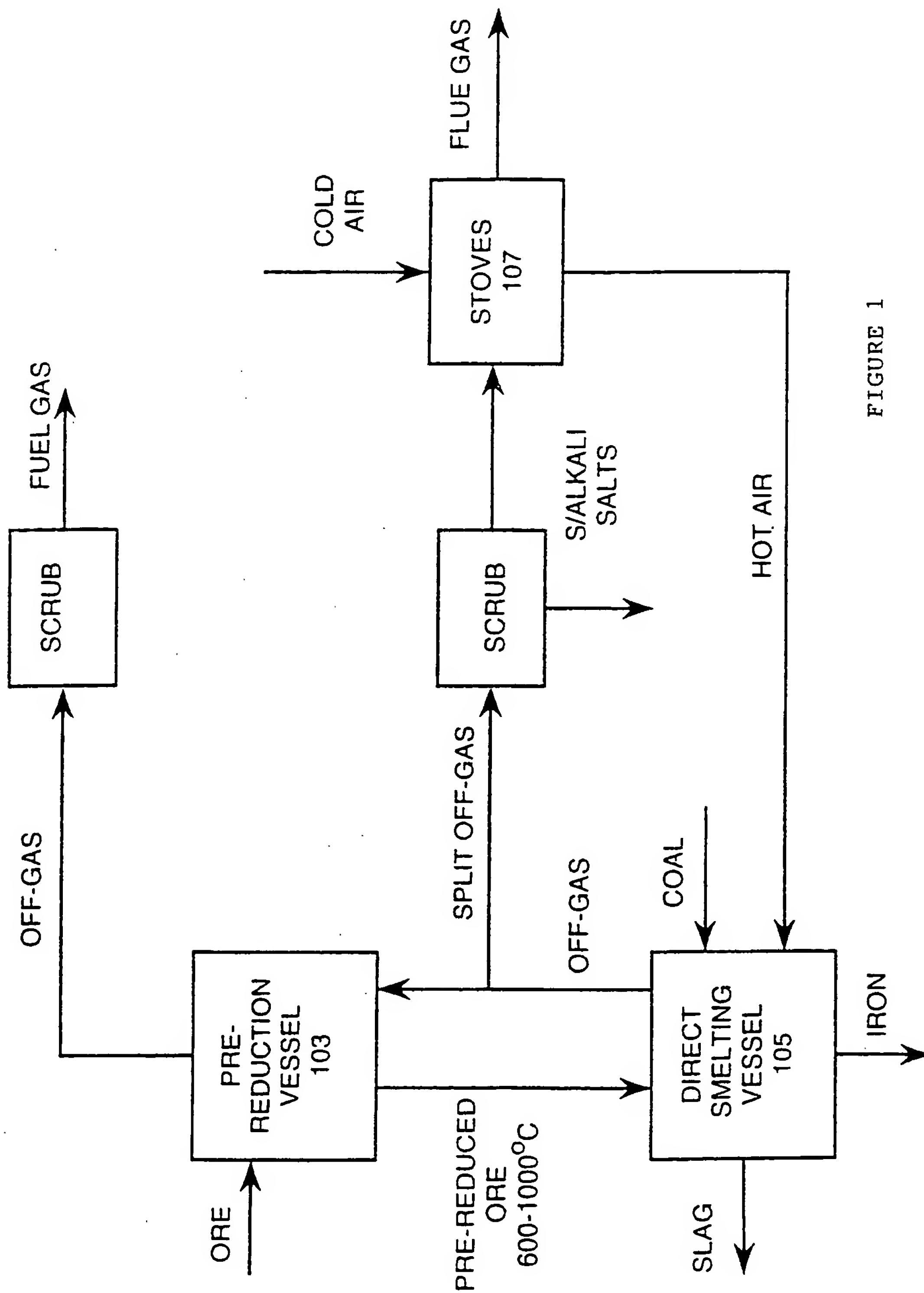


FIGURE 1

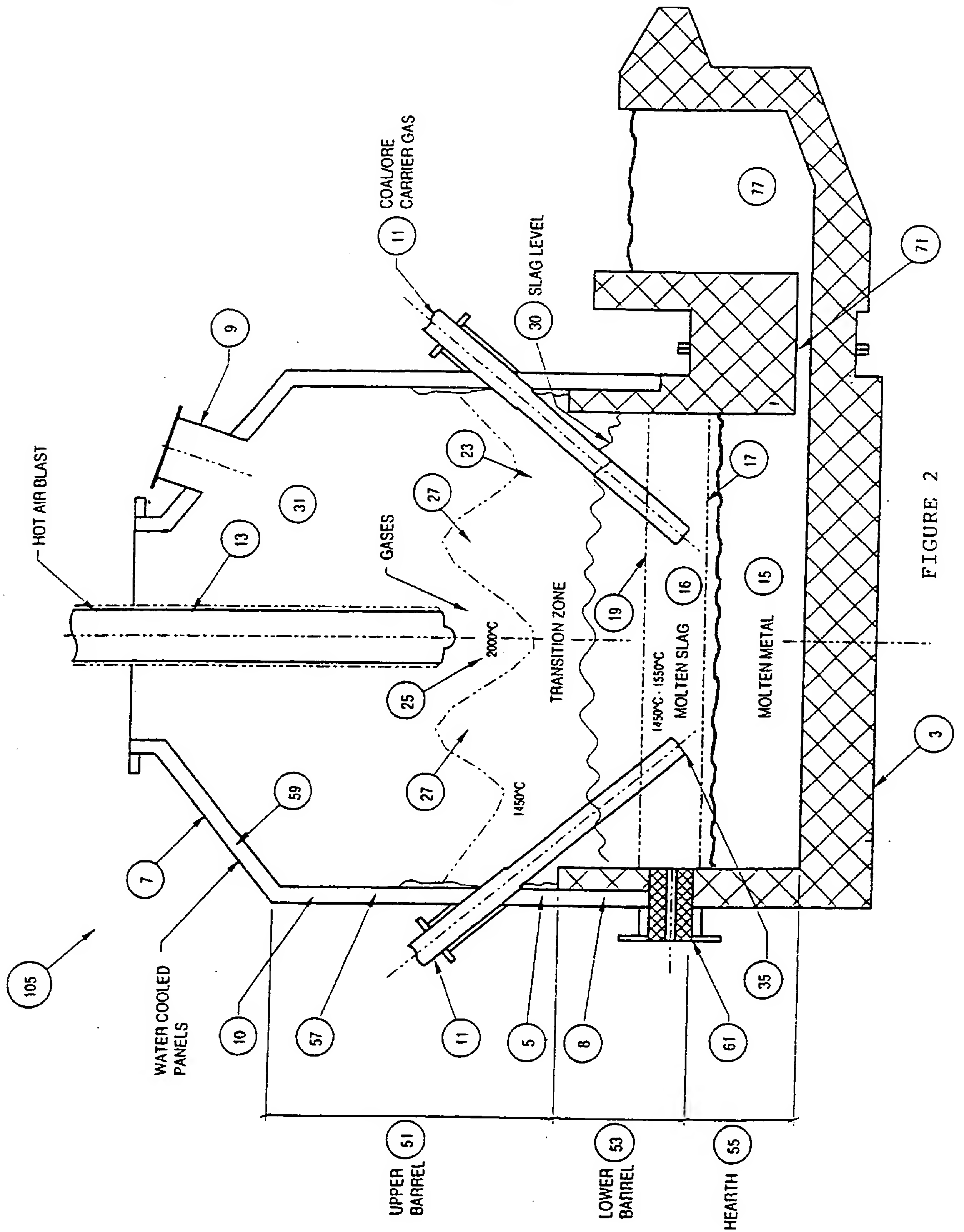


FIGURE 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU00/00938

A. CLASSIFICATION OF SUBJECT MATTER												
Int. Cl. ⁷ : C21B 11/00, 11/02, 13/00, 13/14												
According to International Patent Classification (IPC) or to both national classification and IPC												
B. FIELDS SEARCHED												
Minimum documentation searched (classification system followed by classification symbols) IPC C21B 11/00, 11/02, 13/00, 13/14												
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched												
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) DWPI SULFUR OR SULPHUR												
C. DOCUMENTS CONSIDERED TO BE RELEVANT												
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.										
X	US 4804408 A (PÜHRINGER et al.) 14 February 1989	1, 3										
X	US 5630862 A (GREENWALT) 20 May 1997	1										
X	US 5871560 A (FLUCH et al.) 16 February 1999	1										
A	US 5683489 A (HAYASHI et al.) 4 November 1997	1										
<input type="checkbox"/> Further documents are listed in the continuation of Box C <input checked="" type="checkbox"/> See patent family annex												
<p>* Special categories of cited documents:</p> <table border="0"> <tr> <td>"A" document defining the general state of the art which is not considered to be of particular relevance</td> <td>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</td> </tr> <tr> <td>"E" earlier application or patent but published on or after the international filing date</td> <td>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</td> </tr> <tr> <td>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</td> <td>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</td> </tr> <tr> <td>"O" document referring to an oral disclosure, use, exhibition or other means</td> <td>"&" document member of the same patent family</td> </tr> <tr> <td>"P" document published prior to the international filing date but later than the priority date claimed</td> <td></td> </tr> </table>			"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family	"P" document published prior to the international filing date but later than the priority date claimed	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention											
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone											
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art											
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family											
"P" document published prior to the international filing date but later than the priority date claimed												
Date of the actual completion of the international search 6 September 2000		Date of mailing of the international search report 12 SEP 2000										
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaaustralia.gov.au Facsimile No. (02) 6285 3929		Authorized officer R.P. ALLEN Telephone No : (02) 6283 2134										

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU00/00938

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member			
US	4804408	AU	76177/87	BR	8704134	CA	1333336
		DD	261379	EP	257173	JP	63047320
		SU	1743360	ZA	8705914		
US	5630862	CA	2107544	US	5259864	WO	9408055
		US	5259865	US	5320676	US	5354356
		US	5380352	US	5397376	US	5429658
		US	5338336	US	5470375		
US	5871560	AT	1248/94	AU	25568/95	BR	9508108
		CA	2193855	EP	766747	WO	9600302
		ZA	9505177				
US	5683489	AU	42052/96	JP	8198613		
END OF ANNEX							